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LOW-SPEED FREE-FLIGHT STABILITY AND DRAG CHARACTERISTICS OF RADIALLY VENTED PARACHUTES

by Sanger M. Burk, Jr.

Langley Research Center
Langley Station, Hampton, Va.

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Technical Film Supplement L-817 available on request.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

A drop-test investigation has been conducted to determine the stability and drag characteristics of radially vented (duplex) parachutes. Parachutes of two different designs were tested: a large parachute with high geometric porosity and a small parachute with low geometric porosity designed for the same descent velocity with the same load. The results of the tests show that the large high-porosity duplex parachute was very stable in descent, oscillations averaging about $\pm 3.4^{\circ}$; and the average drag coefficients based on the total canopy area and based on the fabric area alone were approximately 0.38 and 0.55, respectively. The small, low-porosity duplex parachute was also very stable in descent, oscillations averaging about $\pm 4.5^{\circ}$; and the average drag coefficients based on the total canopy area and based on the fabric area alone were approximately 0.62 and 0.79, respectively. The oscillations for the cluster of three solid flat circular parachutes, tested for comparison purposes, were $\pm 7.1^{\circ}$. The average drag coefficients based on the total canopy area and the fabric area alone were approximately 0.64 and 0.65, respectively.

INTRODUCTION

The National Aeronautics and Space Administration Langley Research Center is conducting a research program to evaluate different types of recovery systems for aircraft, spacecraft, and boosters. As part of this program, an investigation has been made to evaluate the stability and drag characteristics of radially vented parachutes. Reinhold J. Gross of Wright-Patterson Air Force Base devised this new type of parachute, called the duplex parachute, to have the following characteristics: (1) a high degree of stability, (2) a reasonably high drag coefficient, (3) lightweight, (4) fairly simple construction, (5) reliable deployment, and (6) low opening shock loads. The parachute is called a duplex parachute because, in general, it is similar to a combination of a solid flat circular parachute and a ring-slot parachute. The solid flat circular and ring-slot parachutes are conventional parachutes and are described in detail in reference 1. Two types of duplex parachutes were designed. One type consisted of alternate solid gores of parachute fabric and gores constructed of wide fabric strips with large intervening slots. The second type is similar to the first except that there are two solid gores of parachute fabric between each gore of fabric strips. The idea behind this parachute design is to have gores with large slots to provide high stability and relatively low opening shock loads and solid gores (with low fabric porosity) to provide high drag and good opening reliability.

In the present investigation the two different configurations of the duplex parachute were tested in free flight by dropping them from a helicopter. For comparison purposes, a cluster of three solid flat circular parachutes also was tested. The investigation, in addition to determination of the stability and drag characteristics of the parachutes, also included the determination of the filling times of the parachutes.

SYMBOLS

$C_{D,O}$ drag coefficient of parachute based on total fabric area, D/qS_O

$C_{D,t}$ drag coefficient of parachute based on total canopy area including any slots or vents, D/qS_t

D drag of parachute (at steady rate of descent, drag is equal to weight of parachute plus its payload), lb

q dynamic pressure, $\rho V^2/2$, lb/sq ft

ρ air density, slugs/cu ft

V rate of vertical descent, ft/sec

S_O total fabric area of canopy, sq ft

S_t total canopy area including any slots or vents, sq ft

PARACHUTE CONSTRUCTION

For the tests in the present investigation, six duplex parachutes and three clusters of three solid flat circular parachutes were used. Photographs of the parachutes are shown in figures 1 and 2.

The duplex parachutes were of the flat circular type with a center orifice, and radially placed vents, and included pocket bands. The latter are small fabric strips attached to the canopy skirt between adjacent skirt sections across the suspension lines (see ref. 1 for details) and, in general, improve the opening characteristics of the parachute. Three of the duplex parachutes were of the type shown in figure 3(a). They consisted of alternate solid gores of parachute fabric and gores constructed of wide fabric strips with intervening air slots. The other three duplex parachutes were of the type shown in figure 3(b). In these parachutes, two solid gores of fabric were alternated with single gores of fabric strips.

The clustered parachutes were of the solid flat circular type with central orifices and pocket bands. Details of the gores of these parachutes are shown in figure 3(c). All the parachutes (duplex and clustered) were designed to have approximately the same drag, that is, to give approximately the same rates of descent with the same load. As a result of this design condition, the average diameters of the various parachutes are as follows: 37.8 feet for the duplex parachutes with every second gore constructed of fabric strips, 32.0 feet for the duplex parachutes with every third gore constructed of fabric strips, and 17.0 feet each for the clustered parachutes. When these dimensions were being determined, the flat canopy was held in sufficient tension to remove the slack in the fabric and associated lines.

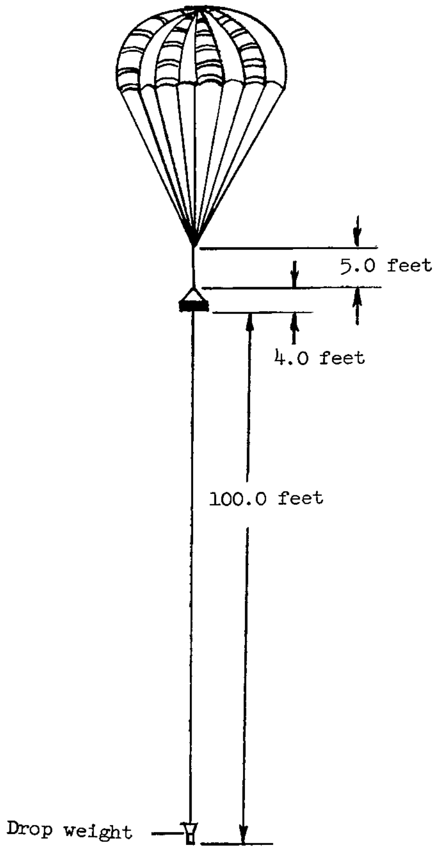
Unless otherwise noted, the 37.8- and 32.0-foot-diameter duplex parachutes are referred to hereafter as the high- and low-porosity duplex parachutes, respectively, since they represent high- and low-porosity approaches to obtain the same descent velocity. The parachute canopies were made of nylon cloth with a fabric porosity between 80 and 120. Fabric porosity is defined as the volume of air in cubic feet that will flow through 1 square foot of cloth in 1 minute at a pressure of 1/2 inch of water. The geometric porosities of the entire parachute canopy for the 37.8-, 32.0-, and 17.0-foot-diameter parachutes were approximately 30.3, 21.0, and 1.0 percent, respectively, the permeability of the fabric itself not being considered. The geometric porosity is defined percentagewise as the ratio of the total area of openings in the canopy (including vent area) to the total area of the canopy S_t.

For the stability tests the payload weight which was about 194 pounds was attached to both types of duplex parachutes by a riser which was $49\frac{1}{2}$ feet in length and to the clustered parachutes by risers 48.0 feet in length. (See fig. 4.) For the drag tests the payload weight was about 180 pounds and the length of the risers on all the parachutes was shortened to 5.0 feet.

TESTING TECHNIQUE

The free-flight tests of the parachutes were performed at an isolated area near Langley Air Force Base, Virginia. The tracking equipment used in the present investigation is somewhat similar to that described in reference 2. In brief, two ground stations similar to those shown in figure 5 were used to track the parachutes. Each ground station was provided with a motorized tracking unit equipped with a telephoto motion-picture camera and binoculars to assist the observers and trackers in viewing the behavior of the parachute. The cameras were operated at 24 frames per second.

A helicopter equipped with a special launching rig was used to drop the parachutes. When the payload was released from the hovering helicopter, it pulled the parachute out of a bag which was retained by a 4-foot static line attached to the helicopter. For the drag tests only, a 100-foot line (referred to as a dropline) was attached to the bottom of the payload, and at its lower end a small weight was attached (weight plus dropline equals 1.75 pounds) to keep the drop line straight while the parachute was descending. (See sketch (a).) When the small weight contacted the ground, three observers started stop watches and recorded the time until the main payload struck the ground in order to determine the rate of descent.



Sketch (a)

TESTS

For the tests to determine the stability characteristics of the parachutes, the parachutes were dropped from altitudes ranging from approximately 1,500 to 1,700 feet with the helicopter in a near-hovering condition. A total of nine parachute drops were made. The wind velocities during these tests were steady at about 10 to 15 knots.

For the parachute drag tests, the parachutes were dropped from altitudes ranging from 800 to 1,000 feet with the helicopter in a near-hovering condition. The wind velocities on the test day were light and variable and less than 5 knots. A total of seven parachute drops were conducted. These tests consisted of dropping two low-porosity duplex parachutes, four high-porosity duplex parachutes, and one clustered parachute design.

For more detailed information on the drop conditions for the stability and drag tests, see tables I and II.

REDUCTION OF DATA

The stability characteristics of the parachutes were determined by measuring the deflections of the risers from the vertical as recorded on motion-picture film obtained from ground-based cameras. The measurements of the oscillations were begun after the oscillations due to initial canopy inflation had damped out and continued until some appropriate distance above the ground where the measurements were terminated to avoid the possibility of erratic effects due to variable ground winds. The maximum amplitudes of the parachute oscillations were measured only when the oscillations were in approximately the same plane as the projected image and then were averaged for each drop test as shown in table I. No corrections were made to the measurements of the parachute oscillations although the principal axis of the camera lens (which was continuously changing in elevation as the descending parachute was tracked) was never perpendicular to the nearly vertical path along which the parachutes descended. However, it is felt that the differences between the apparent oscillation angles and the true oscillation angles are small since the elevation angles of the principal axis of the camera were small. Also the results are considered to be conservative since the oscillation angles, when measured on film, appear slightly larger than the true oscillation angles.

The filling times of the parachutes were obtained from motion-picture film and were measured from the instant the parachutes were completely out of the bag until they were fully inflated.

In order to obtain the drag coefficients of the parachutes, it was necessary to determine the rates of descents of the parachutes. As previously mentioned, stop watches were used to obtain the time for the parachutes to descend a known distance. These times were then averaged to obtain the rate of descent.

RESULTS AND DISCUSSION

A motion-picture film supplement covering some of the drop tests of the parachutes which are considered to be typical of the results obtained has been prepared and is available on loan. A request card and a description of the film will be found at the back of this paper on the page preceding the abstract cards. The results of the parachute stability and drag tests are presented in tables I and III, respectively.

Stability Characteristics

The results of the stability tests show that both types of duplex parachutes were very stable in descent. The high-porosity duplex parachutes had oscillations averaging about $\pm 3.4^{\circ}$ while the low-porosity duplex parachutes had oscillations averaging about $\pm 4.5^{\circ}$. The high-porosity duplex parachute was evidently slightly more stable than the low-porosity one because of its greater geometric porosity, since this is the normal effect of porosity. Two of the high-porosity parachutes rotated very slowly, one to the left, and one to the right, at approximately 3 revolutions per minute while descending. The third high-porosity parachute did not rotate and the canopy exhibited an unusual motion. The canopy if viewed from above would appear to consist of two halves with each half oscillating in rotation very slightly about a vertical axis through the center of the parachute vent. The canopy halves rotated in unison, one clockwise and the other counterclockwise, and thus alternately compressed and stretched the gores with fabric strips. This motion is shown in the motion-picture film supplement. No such rotation or unusual motions were noted for the low-porosity parachutes. The cluster of three solid flat circular parachutes was fairly stable in descent, oscillations averaging about $\pm 7.1^{\circ}$.

The risers on the parachutes tested in the present investigation, in general, were made longer than those normally used on parachutes of these sizes in order to allow the parachutes to drift slightly after the payload has contacted the ground. This drifting of the parachutes (a slight wind being assumed) will tend to prevent the parachutes from settling on and covering the payload, which is a very important consideration in many practical operations. In order to determine whether the long risers affected the stability of the parachutes, a more normal length riser (5-foot length) was attached to one of the low-porosity duplex parachutes for one test. The results indicated that the parachute had oscillations averaging about $\pm 4.7^{\circ}$ which was about the same as the amplitude obtained with a long riser.

Drag Characteristics

The results of the drag tests (table III) show that the average drag coefficient of the high-porosity duplex parachutes based on the total canopy area and based on the fabric area alone were approximately 0.38 and 0.55, respectively. For the low-porosity duplex parachutes, the average drag coefficient based on the total canopy area and based on the fabric area alone were about 0.62 and 0.79, respectively. It should be noted that the drag coefficient for drop 1 was not averaged with those for the other drops of the high-porosity duplex parachutes since the value for this particular drop was far out of line with the data from other drops and was not considered typical for this type of parachute. The reason for this discrepancy is not known, but when this parachute was observed during the tests (the same parachute was dropped again as drop 4), it had a descent velocity and drag coefficient more similar to those obtained for the other high-porosity duplex parachutes.

The average drag coefficients of the clustered parachutes based on the total canopy area and based on the fabric areas alone were approximately 0.64 and 0.65, respectively.

Filling Time

The parachutes were opened at relatively low velocities since they were dropped from a hovering helicopter at low altitudes. The filling times are obviously a function of the velocities at which the parachutes are deployed and since these velocities were not measured, the filling times measured in the tests are not significant in absolute quantitative terms. However, the filling times should give an indication as to the relative filling times of the three different types of parachutes. The filling times of the parachutes are presented in table I and show that the filling time for the high-porosity duplex parachutes ranged from 5.4 seconds to 6.2 seconds, and for the low-porosity duplex parachutes from 2.5 seconds to 3.1 seconds. The filling time for the clustered parachutes was approximately 1.2 seconds. These results show that, as might be expected, the filling times for the large high-porosity parachutes were greater than those for the other two types of parachutes tested.

SUMMARY OF RESULTS

The results of a free-flight investigation to determine the stability and drag characteristics of a duplex parachute design may be summarized as follows:

1. The high-porosity duplex parachute (37.8-foot diameter) was very stable in descent, oscillations averaging about $\pm 3.4^{\circ}$. The average drag coefficients based on the total canopy area and based on the fabric area alone were approximately 0.38 and 0.55, respectively.

2. The low-porosity duplex parachute (32.0-foot diameter) was very stable in descent, oscillations averaging about $\pm 4.5^{\circ}$. The average drag coefficients based on the total canopy area and based on the fabric area alone were approximately 0.62 and 0.79, respectively.

3. The cluster of three solid flat circular parachutes used to afford a basis for comparison was fairly stable in descent, oscillations averaging $\pm 7.1^{\circ}$. The average drag coefficients based on the total canopy area and the fabric area alone were approximately 0.64 and 0.65, respectively.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., February 7, 1964.

REFERENCES

1. Anon.: United States Air Force Parachute Handbook. WADC Tech. Rep. 55-265, ASTIA Doc. No. AD 118036, U.S. Air Force, Dec. 1956.

2. Libbey, Charles E., and Burk, Sanger M., Jr.: A Technique Utilizing Free-Flying Radio-Controlled Models To Study the Incipient- and Developed-Spin Characteristics of Airplanes. NASA MEMO 2-6-59L, 1959.

TABLE I.- SUMMARY OF TEST CONDITIONS AND RESULTS REGARDING STABILITY CHARACTERISTICS AND FILLING TIME OF DUPLEX AND CLUSTERED PARACHUTES

Drop	Parachute type	Parachute diameter, ft	Parachute weight, lb	Payload weight, lb	Riser length, ft	Drop altitude, ft	Filling time, sec	Average oscillation angle for each parachute, deg	Average oscillation angle for each type of parachute, deg
1	High-porosity duplex	37.8	14.5	192.0	49.5	1,700	6.2	±2.8	±3.4
2		37.8	14.5	192.0	49.5	1,740	5.4	±2.3	
3		37.8	14.5	188.0	49.5	1,700	5.5	±5.2	
4	Low-porosity duplex	32.0	11.5	198.0	49.5	1,700	2.5	±4.8	±4.5
5		32.0	11.5	189.0	49.5	1,490	3.1	±5.3	
6		32.0	11.5	192.0	49.5	1,700	2.5	±3.7	
7		32.0	11.5	188.0	5.0	2,000	3.2	±4.7	
8	Cluster (3 solid flat circular)	17.0	14.7	192.0	48.0	1,600	1.2	±6.9	±7.1
9		17.0	14.7	198.0	48.00	1,740	1.2	±7.3	

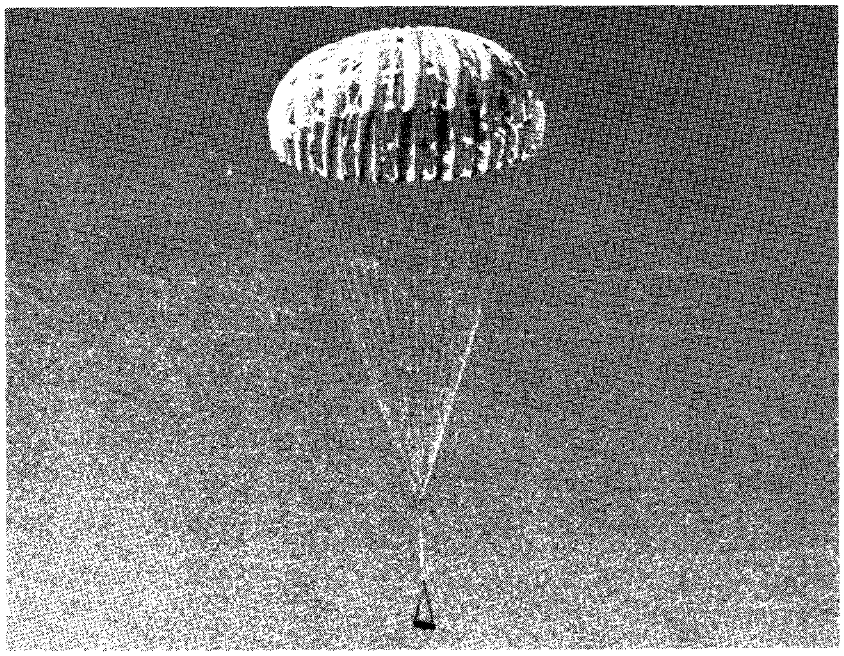
TABLE II.- SUMMARY OF TEST CONDITIONS REGARDING DRAG CHARACTERISTICS

OF DUPLEX AND CLUSTERED PARACHUTES

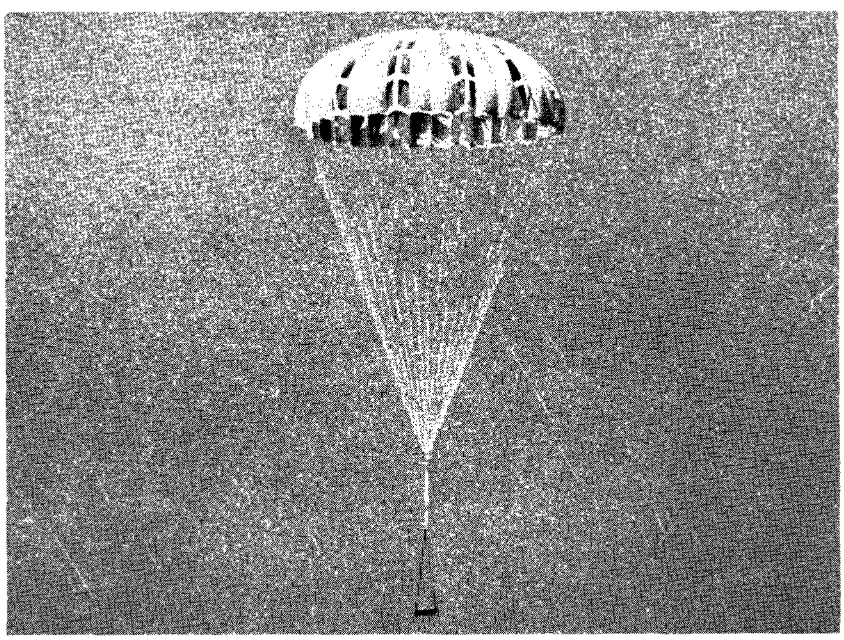
Drop	Parachute type	Parachute diameter, ft	Parachute weight, lb	Payload weight, lb	Riser length, ft	Dropline and drop weight, lb	Dropline length, ft	Drop altitude, ft
1	High-porosity duplex	37.8	14.5	188.0	5.0	1.75	100.0	800
2		37.8	14.5	188.0	5.0	1.75	100.0	950
3		37.8	14.5	188.0	5.0	1.75	100.0	1,000
4		37.8	14.5	188.0	5.0	1.75	100.0	1,000
5	Low-porosity duplex	32.0	11.5	188.0	5.0	1.75	100.0	900
6		32.0	11.5	188.0	5.0	1.75	100.0	1,000
7	Cluster (3 solid flat circular)	17.0	14.7	188.0	5.0	1.75	100.0	1,000

TABLE III.- SUMMARY OF RESULTS REGARDING DRAG CHARACTERISTICS OF DUPLEX AND CLUSTERED PARACHUTES

Drop	Parachute type	Parachute diameter, ft	Time for payload to descend vertically 100 feet, sec			Average time, sec	Rate of descent, ft/sec	$C_{D,t}$ for each parachute	Average $C_{D,t}$ for each type of parachute	$C_{D,O}$ for each parachute	Average $C_{D,O}$ for each type of parachute
			Observer 1	Observer 2	Observer 3						
1		37.8	6.25	6.30	6.40	6.32	15.8	0.61	----	0.87	----
2	High-porosity duplex	37.8	5.30	5.05	5.10	5.15	19.4	0.40		0.58	
3		37.8	5.10	4.90	4.80	4.93	20.3	0.37	0.38	0.53	0.55
4		37.8	5.00	5.10	4.90	5.00	20.0	0.38		0.54	
5	Low-porosity duplex	32.0	5.30	5.20	5.40	5.30	18.9	0.58	0.62	0.74	0.79
6		32.0	5.60	5.70	5.60	5.63	17.8	0.66		0.83	
7	Cluster (3 solid flat circular)	17.0	----	5.00	5.10	5.05	19.8	0.64	0.64	0.65	0.65



(a) High porosity (37.8-foot diameter).



(b) Low porosity (32.0-foot diameter). L-64-377

Figure 1.- Photographs of duplex parachutes in free flight.

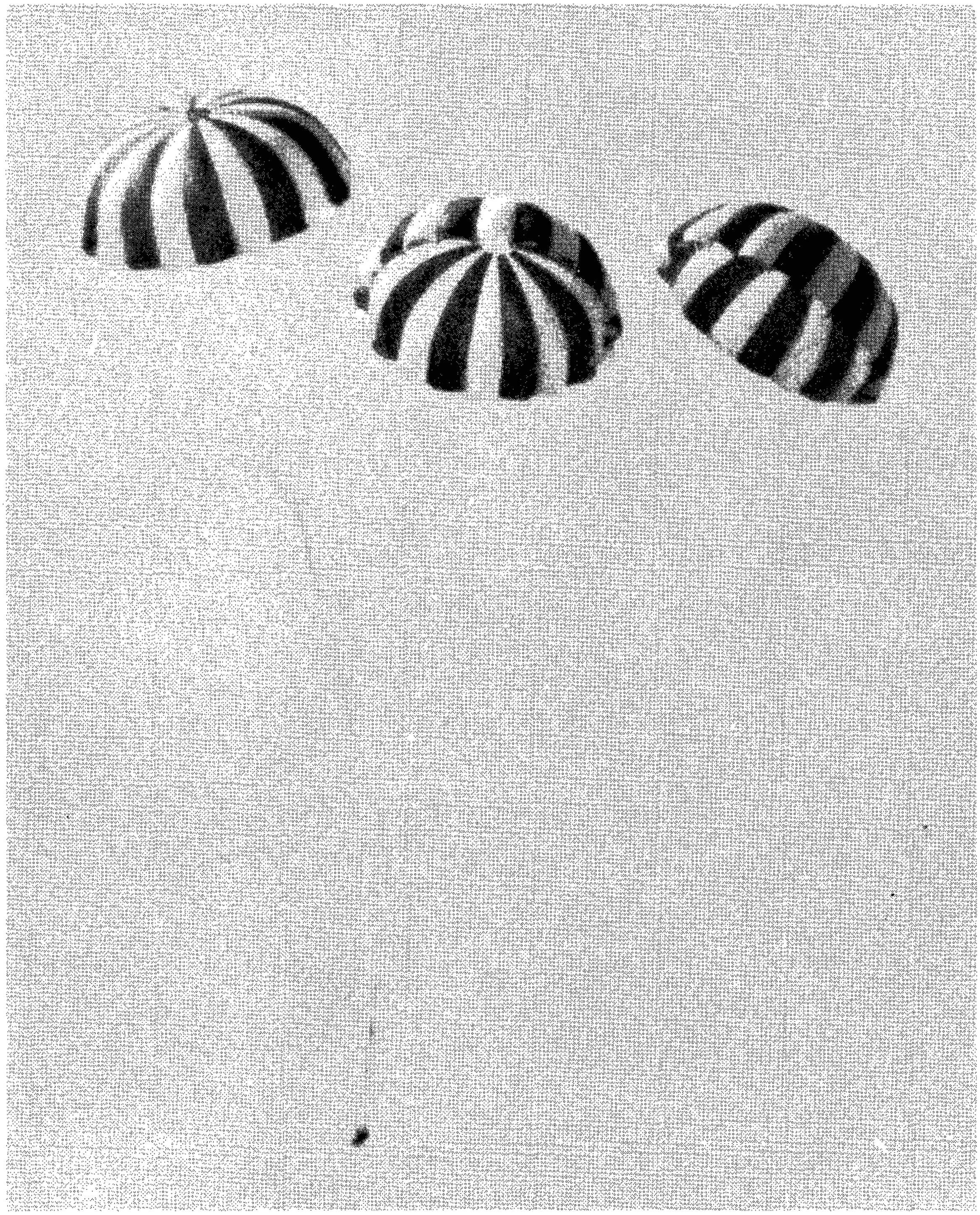


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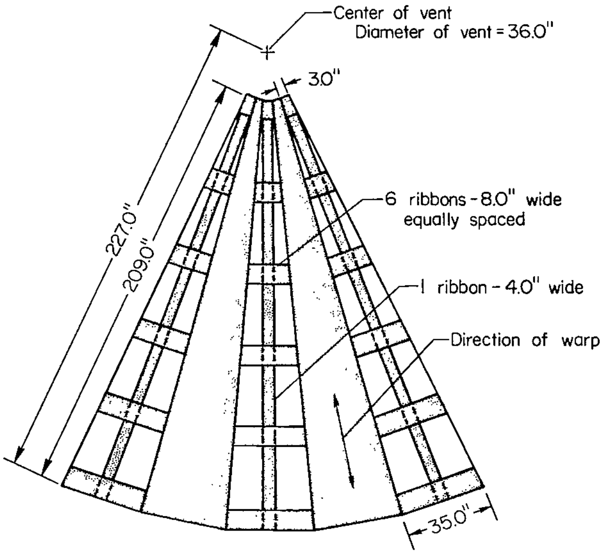
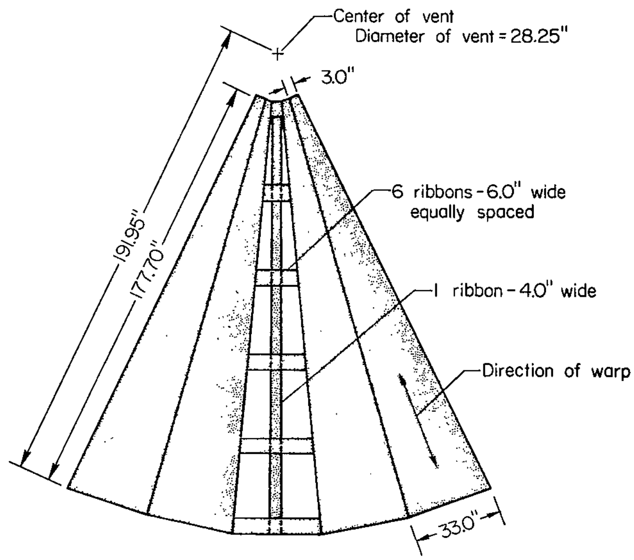
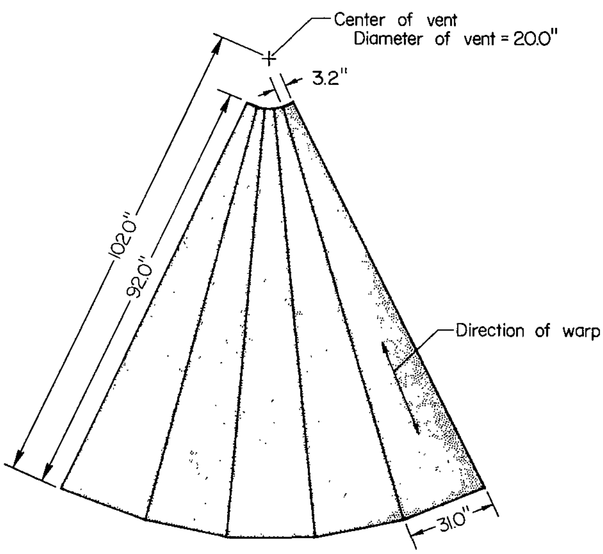
Figure 2.- Photograph of clustered solid flat circular parachutes in free flight.



(a) High-porosity 37.8-foot-diameter duplex parachute showing 5 of 40 gores (20 solid fabric gores and 20 open ribbon gores).

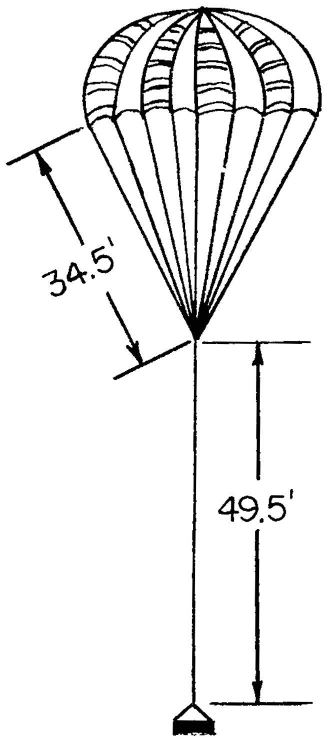


(b) Low-porosity 32.0-foot-diameter duplex parachute showing 5 of 36 gores (24 solid fabric gores and 12 open ribbon gores).

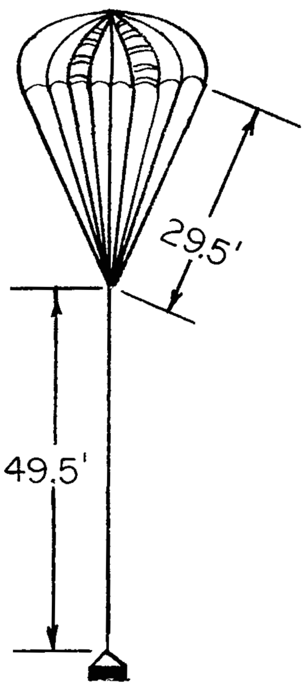


(c) 17.0-foot-diameter solid flat circular parachute showing 5 of the 20 gores.

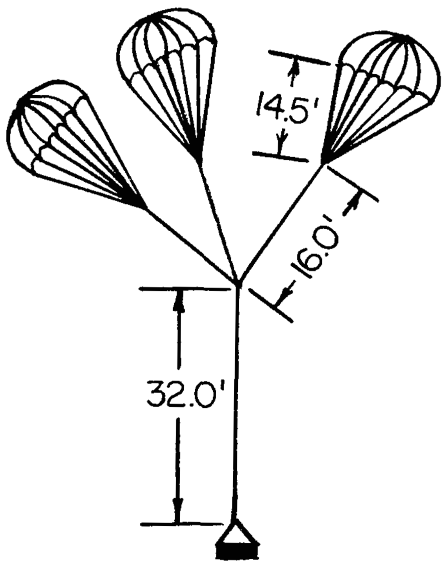
Figure 3.- Gore details of parachutes.



(a) High-porosity 37.8-foot-diameter duplex parachute.



(b) Low-porosity 32.0-foot-diameter duplex parachute.



(c) Clustered 17.0-foot-diameter solid flat circular parachutes.

Figure 4.- Sketch showing riser and suspension-line lengths of parachutes used in stability tests.

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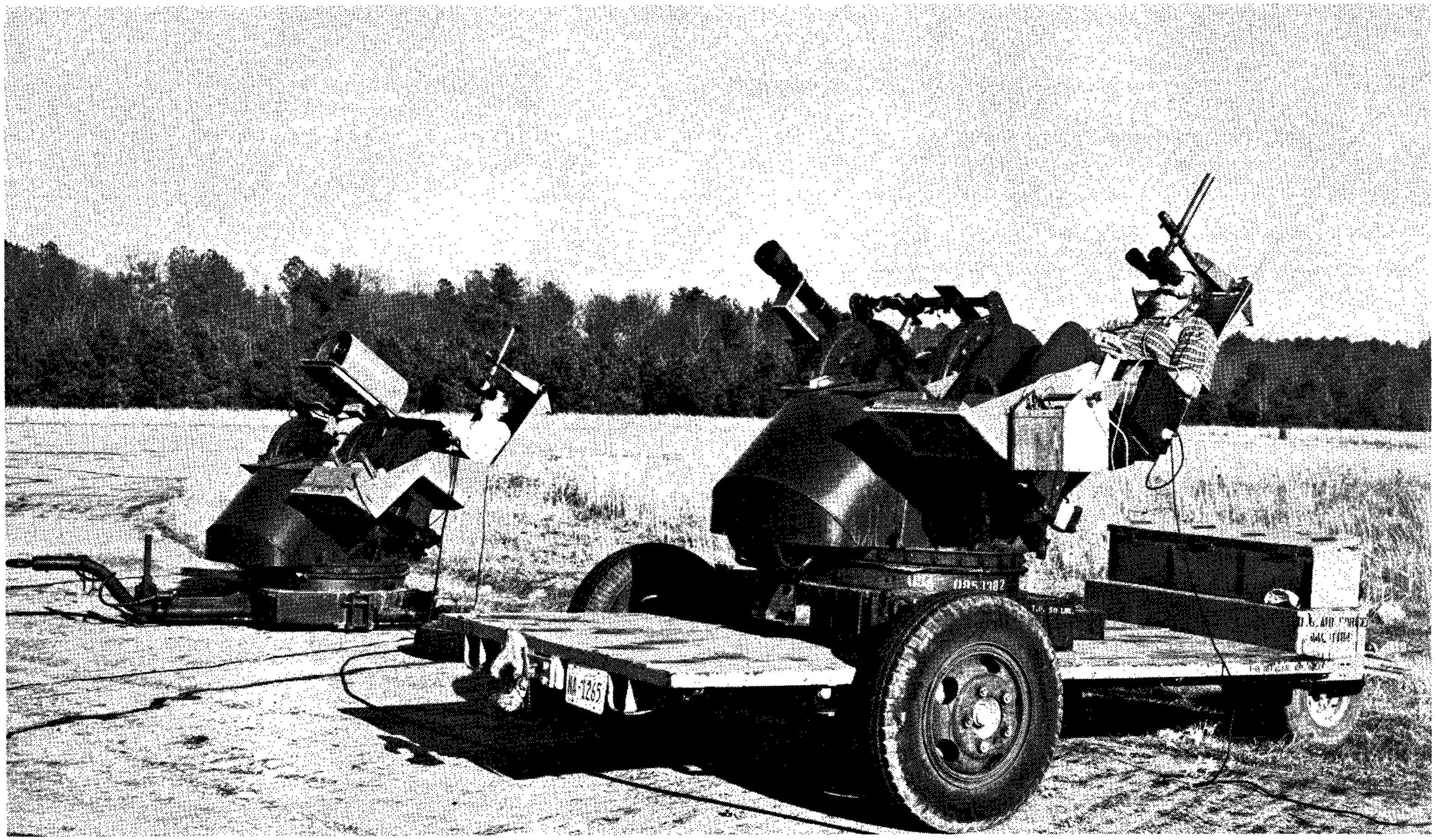

Figure 5.- Photograph of ground stations. L-60-1879

A motion-picture film supplement L-817 is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The film (16 mm, 15 min, color, silent) shows the low-speed stability and drag characteristics of radially vented parachutes in free flight. Also included for comparison purposes are tests of a cluster of three solid flat circular parachutes.

Requests for the film should be addressed to:

Chief, Photographic Division
NASA Langley Research Center
Langley Station
Hampton, Va. 23365

C U T

Date ________________

Please send, on loan, copy of film supplement L-817 to TN D-2271.

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